Nicolle
6-11-03

TITLE

VOLTAGE BLOCK AND COLOR CHANGE APPARATUS FOR WATERBORNE BELL APPLICATOR

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. provisional patent application serial no. 60/251,686, filed December 7, 2000, and U.S. provisional patent application serial no. 60/291,232, filed May 16, 2001.

BACKGROUND OF THE INVENTION

The present invention relates generally to robotic paint applicators and, particularly to an apparatus for changing the paint color for a waterborne bell applicator.

Robotic paint applicators for assembly lines are well known in the art. In order to be most efficient on a vehicle assembly line, for example, the robotic paint applicators must be able to paint with a variety of different colors changing as the objects to be painted are presented. A problem found in the prior art waterborne paint bell applicators when changing paint colors was a high cycle time. Cycle time is the amount of time needed to change from a current paint color to a new paint color, measured from the time the applicator stops painting with the paint color currently being applied to the time it starts painting with a different paint color. During this cycle time, the high voltage power supply must be disconnected, the internal passages and the external shroud of the bell applicator must be cleaned and the applicator must be connected with a source of the new paint color. Prior art applicators accomplished the color change by either switching connections between separate remote storage tanks for the current color paint and the new color paint, swapping an on board canister of the current color paint for a substitute canister filled with the new color paint, or cleaning the current color paint from the on board canister and filling it with the new color paint.

The U.S. Patent No. 4,785,760 shows a sprayer installation having a paint sprayer carried by a robot with an arm for spraying objects carried by a conveyor. Circuits for distributing products to be sprayed each have first connection means at fixed locations within the range of the robot. A storage tank connected to the sprayer is carried by the robot and communicates with a first complementary connection means. The first

complementary connection means is co-operable with the first connection means of any of the distribution circuits during which time the high voltage is turned off. The storage tank can be retained on the arm or can be exchanged for a filled tank at the first connection means.

The U.S. Patent No. 5,772,125 shows a machine for spraying a coating material which machine includes a sprayer, an on-board supply tank having first connection means, a coating material changing assembly having second connection means, and a mobile subassembly carrying the sprayer, the supply tank and the changing assembly. At least one of the connection means is movable between a coupling position and an isolated position relative to the other connection means.

The art continues to seek improvements in reducing both the cycle time and in the amount of wasted paint during a color change operation. Reducing the cycle time increases both painting capacity and production capacity because more objects can be painted in a given amount of time. Reducing the amount of paint used by the robotic paint applicator represents an obvious cost savings.

SUMMARY OF THE INVENTION

The present invention concerns a bell applicator for reducing a cycle time for refilling or changing a paint color. The bell applicator according to the present invention accomplishes this by combining some of the necessary steps in the cycle time. First, the paint applicator internals are cleaned while the applicator is en route to filling station. After the applicator arrives at the filling station, the external shroud is cleaned at the same time that the canister is being refilled with a new paint color.

The bell applicator according to the present invention also reduces the amount of wasted/excess paint that is common in the prior art applicators. The bell applicator according to the present invention is fed by an internal canister and is carried on the robot wrist. The applicator docks with a paint filling station that can supply multiple colors and is mounted either on the robot carriage or turret and thus moves with the robot, or at a fixed location in the booth within the reach of the robot.

The filling station has a plurality of paint injectors, one for each color, that can be selectively moved to a docking position to engage a paint receptacle on the applicator. The bell applicator external shroud can be washed while the canister is being filled. This color

change approach offers cycle time and paint savings. The design alternative of using the robot to position the applicator to engage with a fixed injector is less favorable due to limitations of the robot reach and dexterity while rotating a typical 60-degree bell applicator in a filling station.

The bell applicator according to the present invention also incorporates provisions onboard the robot to clean the internal paint supply components including the canister, the cup and the distributor. An automatic valve mounted on the robot is designed to alternately control the supply of cleaning fluids to the uncharged bell or electrically isolate supply and dump lines from a charged bell. The bell can be cleaned en-route to the filling station thus reducing cycle time.

DESCRIPTION OF THE DRAWINGS

The above, as well as other advantages of the present invention, will become readily apparent to those skilled in the art from the following detailed description of a preferred embodiment when considered in the light of the accompanying drawings in which:

Fig. 1 is a perspective view of a bell applicator painting robot having a voltage block and color change apparatus in accordance with the present invention;

Fig. 2 is a perspective view of a first embodiment filling station for use with the apparatus shown in Fig. 1;

Fig. 3 is a perspective view of a second embodiment filling station for use with the apparatus shown in Fig. 1;

Fig. 4 is perspective view of a third embodiment filling station for use with the apparatus shown in Fig. 1;

Fig. 5 is an enlarged schematic cross-sectional view of the manifold and paint injector shown in Fig. 1;

Fig. 6 is a schematic cross-sectional view of the robot arm with bell applicator and the paint injector shown in Fig. 1;

Fig. 7 is an enlarged cross-sectional view of the paint injector shown in Fig. 5;

Fig. 8 is a cross-sectional view of the fluid control valve shown in Fig. 6;

Fig. 9 is a table of the operating sequence of the voltage block and color change apparatus according to the present invention;

Fig. 10 is a perspective view similar to Fig. 1 showing an alternate mounting location for the voltage block and color change apparatus in accordance with the present invention;

Fig. 11 is perspective view of a fourth embodiment filling station for use with the apparatus shown in Fig. 1;

Fig. 12 is a cross-sectional view of a prior art bell applicator and Fig. 12A is an enlarged portion of Fig. 12;

Fig. 13 is a cross-sectional view of the bell applicator shown in Fig. 1 and Fig. 13A is an enlarged portion of Fig. 13;

Fig. 14 is a cross-sectional view of a robot arm and bell applicator according to the present invention;

Fig. 15 is an enlarged cross-sectional view of the canister servomotor and enclosure shown in Fig. 14;

Fig. 16 is a schematic of the fluid circuits of the bell applicator shown in Fig. 14 and an associated docking station;

Fig. 17 is a table of the operating sequence of the fluid circuits shown in Fig. 16 during a paint color change;

Fig. 18 is a table of the operating sequence of the fluid circuits shown in Fig. 16 during a refill of the same color paint;

Fig. 19 is a perspective view of the bell applicator shown in Fig. 14 with a fifth embodiment filling station; and

Fig. 20 is a cross-sectional view of one of the injectors shown in Fig. 19 with the bell applicator in a docking position.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 1 shows a painting robot **R** having a bell applicator **1** mounted on a robot wrist **2** attached at an end of an arm **A** of the robot. The robot **R** can move the arm **A** to place the applicator **1** inside a filling or docking station **3** that is either fixed in a paint booth **4** or mounted on a carriage **5** of the robot. Multiple paint supply lines **6** feed paint of various colors from storage tanks (not shown) to the filling station **3** and the lines can be selectively connected to fill a paint canister in the arm **A**. The filling station **3** includes a shroud washer **7** that can function as the canister is filled. A fluid control

valve **8** mounted on the robot arm **A** allows the internal paint passages of the bell applicator **1** to be cleaned as the robot **R** moves from a painting position toward the filling station **3** to align a shroud of the bell applicator **1** with the shroud washer **7**. The filling station **3** includes a plurality of paint injectors **11** each connected to an associated one of the paint supply lines **6** for selectively coupling with a bell manifold **30** on the bell applicator **1** for filling the paint canister as described below.

A rotary version of the filling station **3** is shown in more detail in Fig. 2. A first embodiment filling station **3a** fills the canister of the bell applicator **1** with paint of a desired color and washes the shroud **9**. The multiple paint supply lines **6** deliver several colors of paint to the filling station **3a**. Each of the supply lines **6** is connected to an associated one of a plurality of paint injectors **11** arranged in a circular pattern with their engagement axes **12** aligned parallel to each other. The injectors **11** extend upwardly from an upper surface of an annular manifold turntable **13**. The injectors **11** are centered about a vertical axis of rotation of the turntable **13** that is driven in rotation by a rotary indexing means **14**. The shroud washer **7** is centered under the turntable **13** such that the robot **R** can position the shroud **9** in the washer **7** while simultaneously engaging a paint receptacle of the bell manifold **30** (Fig. 1) of the bell applicator **1** with a selected one of the paint injectors **11** that has been rotated to a docking position. The paint supply lines **6** are routed into a single bundle that twists about a rotational axis **15** of the turntable **13**.

An alternate offset rotary arrangement of the injectors **11** is shown in Fig. 3. A second embodiment filling station **3b** has the rotational axis **15** of the turntable **13** offset from an engagement axis **10** of the bell applicator **1** with the shroud washer **7**. This arrangement provides a clear routing path for a shroud washer fluid supply line **56** and a drain line **57** that does not interfere with the paint supply lines **6** as they twist. The paint supply lines **6** can be routed more compactly since the enclosure of the washer **7** does not occupy the same space.

Another or third embodiment filling station **3c** is shown in Fig. 4. A linear arrangement of the injectors **11** is possible for movement along a straight path as indicated by a double-headed arrow **16**. The injectors **11** extend upwardly from an upper surface of a linear manifold **28**. A corresponding linear indexing means **17** drives the manifold **28** to position the selected injector **11** at a docking location. This arrangement

retains the single shroud washer **7** at the docking location and may provide for a more compact and reliable routing of the paint supply lines **6** within a linear cable track **18**.

As shown in Figs. 5 and 6, the injectors **11** are designed to mate with a receptacle **35** formed in the bell manifold **30** mounted on an exterior surface of the bell applicator **1**. The injector **11** is shown in more detail in Fig. 7 and has a hollow valve body **19** with a seat **20** formed at an upper end of a central stem **21** to function as a valve. The valve is opened by supplying air pressure to a lower surface of a pilot piston **22** attached to a lower end of the stem **21**. A spring **23** abuts an upper surface of the piston **22** to close the valve when the air pressure is removed. Radially extending supply port **24** and return port **25** allow unused paint to re-circulate in the supply lines **6**. A face or radial seal **26** on the exterior surface of the body **19** mates with the wall of the bell applicator paint receptacle **35**. A piloting surface **27** formed on the upper end of the valve body **19** engages with a corresponding surface (not shown) of the paint receptacle **35** to align mating components during the docking process. A small burst of solvent and air can be directed from the bell applicator **1** to clean exposed surfaces of the receptacle **35** and the injector **11** as they disengage upon completion of the fill cycle.

As shown in Fig. 6, the fluid control valve **8** is mounted inside a section **29** of the robot arm **A** and is connected by a flexible fluid line **46** to the bell manifold **30** mounted on the bell applicator **1**. The valve **8** controls the flow of cleaning fluids to the manifold **30** and can electrically isolate charged fluid on an output side connected a fluid supply line **31** and an input side connected to a dump line **47**. The manifold **30** includes pilot operated valves **32, 33** and **34** (Fig. 5) connected between a common point and the paint receptacle **35**, an inlet port **36**, and an outlet port **37** respectively. A first short passage **38** (Fig. 6) connects the outlet port **37** with a fluid side of a canister **39** that contains a piston **40** and a drive means **41** for the piston. A second short passage **42** connects the fluid side of the canister **39** to a bell cup **43** of the bell applicator **1**. A trigger valve **44** controls the flow of fluid through the passage **42** from the canister **39** to the bell cup **43**. The shroud **9** surrounds the bell cup **43** and houses shaping air components (not shown). The bell applicator **1** can be docked to one of the paint supply lines **6** controlled by a pilot operated injector valve **48**.

As shown in Fig. 8, the fluid control valve **8** has a moving portion **49**, a stationary portion **50**, and a linear actuation means **51** for reciprocating the portion **49** relative to the

portion **50**. The moving portion **49** includes a supply stem valve **52** and a dump stem valve **53** that feed into a common axial surface surrounded by a face seal **54**. The stationary portion **50** has a stem valve **55** that can block the flow of cleaning fluids out to the bell applicator **1** and allow the mating face of the two ports **49** and **50** to be cleaned prior to disengaging the fluid control valve **8**. An air gap is created between the facing surfaces of the portions **49** and **50** when the valve is disengaged. This air gap insulates the cleaning fluid supply and dump lines from high voltage that is applied to the bell applicator **1** when paint is dispensed. Each of the stem valves **52**, **53** and **55** is air-actuated and spring closed. As a design option, a paint stem valve (not shown) can be added to the moving portion **50** for purposes of supplying paint. The paint stem valve would feed into the common axial surface shared by the other stem valves.

Fig. 9 is a table showing the states of various components of the voltage block and color change apparatus according to the present invention during the clean and fill operation that incorporates the following steps:

a) Painting is completed with green paint.

b) The internal paint supply components and the bell cup are cleaned and the desired paint injector is indexed into position all while the robot is en-route to the filling station. A small amount of cleaning fluid is flushed out the bell cup while the piston is agitated up/down near the end of its stroke.

c) The bell applicator docks with the red paint supply line (the paint receptacle engages with red paint injector).

d) A small amount of red paint is fed to the bell cup with the piston bottomed out.

e) The canister fills with red paint.

f) As the bell applicator releases from the docking station, a small amount of cleaning fluid is ported from the bell applicator to clean the paint receptacle and the injector.

g) The face of the fluid control valve is cleaned and disengaged (block voltage).

h) The robot paints with red paint.

Fig. 10 shows the painting robot **R** with the bell applicator **1** mounted on the robot wrist **2** attached at an end of the arm **A** as depicted in Fig. 1. However, a filling station **3'** is shown mounted in an alternate location on the carriage **5** of the robot. The

filling station **3'** includes the plurality of paint injectors **11** for selectively coupling with the manifold **30** on the bell applicator **1** for filling the paint canister **39** as described above.

A fourth alternate embodiment filling station **3d** is shown in Fig. 11. The injectors **11** extend upwardly from an upper surface of a tubular manifold **60** surrounding the shroud washer **7**. The manifold **60** is mounted on a base **61** for up and down movement as indicated by a double-headed arrow **62**. In an extended position as shown in Fig. 11, the selected injector **11** couples with the bell manifold **30** for filling the canister **39**. In a retracted position shown in dashed line, the injectors **11** are somewhat protected against overspray and physical damage from collisions with the robot arm. In this embodiment, the bell applicator **1** positions the manifold **30** over the selected one of the injectors **11**.

There is shown in Fig. 12 a prior art bell applicator **65** mounted on a wrist **66** of a robot arm **67**. The applicator **65** houses an electric servomotor **68** driving a ball screw **69** that pushes a piston **70** of a paint canister **71**. The prior art bell applicator **65** has several shortcomings. The electric servomotor **68** and attached cabling **72** are potential ignition sources within the hazardous environment of a paint booth. Provisions must be made to isolate the motor **68** and the cabling **72** from the hazardous environment. Explosion proof motors are costly due to a sealed and pressurized enclosure **73** that is required. It is difficult to provide a safe and reliable routing for the electric cable bundle **72** that must flex with the wrist articulation. The cable that passes through the confined space of the hollow wrist **66** is subjected to complex bending and torsion. Cable construction that is approved for hazardous environment is not safe for use under these flexing conditions. Placing the cable **72** inside a pressurized nylon tube **74** (Fig. 12A) increases its overall diameter and stiffness making it difficult to route through the hollow wrist **66**.

It is desirable to minimize the mass and package size of equipment mounted on a robot wrist to reduce the required load capacity of the robot arms and drives and to avoid interference with the work piece and the environment. The prior art electric servomotor **68** packaged at the wrist **66** adds payload to the robot and consumes valuable interior space. The apparatus according to the present invention overcomes these shortcomings.

As shown in Fig. 13, an electric servomotor **80** is located in a robot arm **81** such that it is not part of and does not move with a bell applicator **82** that is attached to a robot

wrist **83**. Rotary motion and torque is delivered from the motor **80** to the bell applicator **82** by a flexible rotary shaft **84** extending through the arm **81**. The shaft **84** flexes to accommodate the wrist axes motion and can be routed through the inside of the hollow wrist **83**. An outer casing **85** of the flexible shaft **84** is bearing **86** mounted to an applicator support housing **87** so that the casing **85** does not twist as a wrist face plate **88** rotates. The motor **80** can be located such that the flexible rotary shaft **84** accommodates the motion of any number of robot arm and wrist axes.

The motor **80** can be positioned inside an existing pressurized enclosure **89** that houses other motors used to drive the robot axes. Using a common enclosure reduces cost. Alternatively, the motor **80** can be located outside the paint booth. Breakage of the grounded flexible rotary shaft **84** is not considered a potential ignition source within the hazardous paint booth environment. Eliminating the motor **80** from the paint applicator assembly reduces the mass and size of the wrist mounted applicator **82** resulting in reduced cost and avoiding electrical cables flexing through the wrist **83**.

Another embodiment of the bell applicator according to the present invention is shown in Figs. 14 and 15 wherein the motor is mounted in an enclosure in the bell applicator and motor wires are placed within sealed and air pressurized nylon tubing as they flex through the robot wrist. A miniaturized purge system with control hardware is placed inside the motor enclosure. An electric servomotor **90** is mounted inside a sealed enclosure **91** on a bell applicator **92** and drives a ball screw assembly **93** that pushes on a piston **94** in a canister **95** to dispense paint to a rotating bell cup **96**. Electric wires **97** connected to the motor **90** are routed inside nylon tubes **98** that flex through a robot wrist **99** along with other service lines that comprise an applicator bundle **100**. One end of each of the nylon tubes **98** is in fluidic connection with the motor enclosure **91**. The other end of each of the tubes **98** is in fluidic connection with an enclosed portion **101** of a robot arm structure **102**. The tubes **98** and the enclosures **91** and **101** are fed pressurized air from an air supply **103** that connects to the arm structure **102**. This arrangement keeps the motor **90**, the wires **97** and associated connections separated from the hazardous spray booth environment.

A purge pressure switch **104** and a maintenance pressure switch **105** are mounted inside the motor enclosure **91** to sense pressure relative to atmosphere. A purge pressure relief valve **106** is mounted in the motor enclosure **91** and a safety pressure relief valve

107 is mounted in the enclosed portion **101**. The purge pressure relief valve **106** cracks open to allow a predetermined amount of fresh air from the air supply **103** to purge the sealed environment. The purge pressure switch **104** confirms internal pressure is above the cracking pressure of the purge relief valve **106**. The maintenance pressure switch **105** detects a nominal internal pressure required to prevent the hazardous spray booth environment from entering the sealed environment. The safety relief valve **107** cracks to protect the sealed environment from an overpressure condition.

A clamp **108** rigidly clamps the bundle **100** to the bell applicator **92** near the robot wrist **99**. The clamp **108** is designed to cluster the bundle lines around a common axis to minimize the motion and strain on the lines. The clamp **108** isolates the connection end of the bundle lines at the applicator **92** from the loads generated as the bundle **100** flexes through the wrist joint **99**. Insulation displacing connectors **109** are used at the arm end of the wires **97** routed inside the nylon tubes **98**. This allows for quick replacement of the flexing wires **97**.

The voltage block and color change apparatus according to the present invention includes an improved filling or docking station and operating sequence as shown in Figs. 16-18. The apparatus includes such improvements as: a shortened on-arm cleaning circuit that can be quickly dried to provide voltage block; a dual "V-shape" injector stack that reduces docking station size; a single solenoid actuated air pilot valve that controls all paint injector valves; and a fail safe design to protect against inadvertently opening an injector.

As shown in Fig. 16, the bell applicator **92** includes a cleaning fluid dump line **111** that is routed directly into a filling or docking station **112** instead of back through the robot arm **102**. This shortens the length of line exposed to high voltage during painting. Tests indicate that a remaining fluid supply line **113** can be dried in an acceptably short time period to achieve sufficient voltage isolation from the grounded robot arm structure **102**.

The bell applicator and docking station fluid circuits shown in Fig. 16 include a plurality of valves **114A** through **114L**. A single solenoid actuated air pilot valve **114K** in the docking station **112** is used to actuate a row of paint injector valves with only two such valves **114F** and **114G** being shown. Air pilot pressure is ported through the valve **114K** to the selected injector from a common supply manifold **115** that docks to the rear

of an injector manifold **116**. The pilot pressure opens the selected injector valve **114F**. The sequence of operation is as follows:

1. A firing cylinder **117** pushes the supply manifold **115** to engage with the injector manifold **116**.

2. The firing cylinder **117** continues to extend until the injector manifold **116** engages with the bell applicator **92**.

3. The remotely located air pilot valve 114K opens to provide pilot pressure to the injector valve **114F**.

4. The injector valve **114F** opens and paint is fed into the bell applicator **92**.

The operation of the valves **114A** through **114L** is set forth in a table of Fig. 17 for a paint color change. The operation of the valves **114A** through **114L** is set forth in a table of Fig. 18 for refilling the canister **95** with the same color paint.

Fig. 19 is a perspective view of the bell applicator **92** in a docking position at the docking station **112**. The station **112** is formed by two vertical rows, a left row **118** and a right row **119**, of stacked injector manifolds **116** in a V-shaped configuration on a support frame. Each of the injectors **116** has an interface surface **120** and an interface axis **121** perpendicular thereto. The two rows **118** and **119** of the paint injectors **116** are oriented such that each injector **116** in one row lies in a common horizontal plane with a corresponding injector **116** of the other row. The interface axes **121** of the two injectors **116** in a common plane intersect a vertical shroud cleaner axis **122** at a common point **123**. This arrangement allows the bell applicator **92** to be centered in the shroud cleaner (not shown) while docked with either row **118** and **119** of the paint injectors **116**. If, for example, the bell applicator **92** is to be docked with the uppermost injector **116** in the right row **119**, the right row is positioned to align the interface axis **121** with the point **123** as shown in Fig. 19. The bell applicator **92** has a docking surface and paint receptacle **124** that is oriented towards the right row **119** into alignment with the interface axis **121**. The firing cylinder **117** associated with the right bank **119** is actuated to push the uppermost paint injector **116** towards the surface/receptacle **124**. This design arrangement reduces the height of the docking station **112** by a factor of two (two rows of injectors versus one row per Fig. 4) while retaining a common shroud cleaner.

As shown in Fig. 20, each of the injector manifolds **116** is mounted on a linear slide **125**. The injector manifold **116** is pneumatically pushed towards the bell applicator

92 in a direction indicated by an arrow **126** against a return spring **127**. This action is carried out by actuation of the firing cylinder **117** to move the supply manifold **115** in a direction of an arrow **127** into engagement with the injector **116** and move both toward the bell applicator **92**. Should the bell applicator **92** not be present at the docking position and the absence of the applicator is not detected and the actuation sequence initiated, then pilot pressure in a passage **128** connected to an injector valve **129** will push the injector manifold **116** off of engagement with the supply manifold **115** and insufficient pilot pressure will be available to open the paint injector valve **129**. Return spring force, travel limits of the firing cylinder **117**, and a contact pressure area **130** on the injector manifold **116** are optimized to achieve this result. This feature prevents paint from the supply from unintentionally spraying out the injector **116** into the booth.

In accordance with the provisions of the patent statutes, the present invention has been described in what is considered to represent its preferred embodiment. However, it should be noted that the invention can be practiced otherwise than as specifically illustrated and described without departing from its spirit or scope.